# STUDY OF THE CHARACTERISTICS OF ARC DISCHARGES

BY

GILBERT HOWARD FETT

B.S. in E.E., University of Illinois, 1931
M.S. Iowa State College, 1932

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN
ENGINEERING IN THE GRADUATE SCHOOL
OF THE UNIVERSITY OF ILLINOIS, 1940

URBANA, ILLINOIS
1940

# STUDY OF THE CHARACTERISTICS OF ARC DISCHARGES

BY

GILBERT HOWARD FETT

B.S. in E.E., University of Illinois, 1931
M.S. Iowa State College, 1932

## AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN
ENGINEERING IN THE GRADUATE SCHOOL
OF THE UNIVERSITY OF ILLINOIS, 1940

URBANA, ILLINOIS
1940

## ACKNOWLEDGMENTS

The author acknowledges the help and suggestions of Professor H. J. Reich who has been greatly interested in the study of glow and arc discharges. He also acknowledges helpful conversations with Professor J. T. Tykociner of the Electrical Engineering Department on the fundamental processes within an arc, with Professor Bruckner of the Mining and Metallurgical Department on the subject of electric welding, and his offer of further cooperation, and with Mr. A. L. Riche of the Micro-Switch Corporation on the commercial aspects of electrode contact material.

The author also acknowledges the receipt of many samples of welding rods from the United States Steel Corporation, Chicago, Illinois, and the samples of contact electrodes from the Micro-Switch Corporation, Freeport, Illinois.

Finally the author is glad to acknowledge his gratitude to his wife for her patience and forbearance while the experimental and theoretical work was going on, and for her help in the typewriting of the report.

## STUDY OF THE CHARACTERISTICS OF ARC DISCHARGES

The arc discharge characteristics studied and described are those concerned with the cathode drop in potential. For the purposes of the study the arc is defined as a low voltage, high current discharge where the voltage drop is of the order of magnitude of the cathode drop of potential.[1] The cathode drop is defined as the difference in potential between the cathode and a point in the arc very near the cathode; the potential gradient over the intervening space between cathode and point is very high, of the order of thousands of volts per centimeter.

Previous methods of measuring the cathode drop of an arc at atmospheric pressure developed the use of a probe after the manner of Langmuir in his studies of glow discharges. The use of a probe in atmospheric arcs is not justified, however, because the presence of a probe disturbs the thermal equilibrium in the arc and requires additional electrical energy from the source.[2]

If electrical contacts are separated the voltage appearing at the instant of separation is shown to be the cathode drop of the resultant arc. The actual voltage might be thought to include not only the cathode drop, but also the anode drop and the contact-resistance drop. The anode drop, however, cannot appear at the instant of separation because the anode drop is set up by the arc to adjust the arc potential to that available from the source. Since the anode contact is in the cathode vicinity at separation, the volume required for the anode drop space charge is non-existant. The contact drop of potential can be shown to be much less than one volt.

The apparatus used in the experiments was an adaptation of that described by Betz and Karrer.[3] A variable speed d-c motor was arranged to rotate a cam which separated contacts at a uniform velocity. The voltage across the contacts at the instant of separation (the cathode drop) was determined by measuring the deflection on the screen of a cathode ray oscillograph. The apparatus was arranged so that the air pressure of the arc could be reduced from one atmosphere to .1 mm. of Hg.

The cathode drop was shown to be (a) independent of the current in the range of .3 ampere to 10 amperes; (b) independent

of the open circuit voltage appearing across the contacts after the arc was extinguished, in the range of 8 to 230 volts; (c) independent of the circuit parameters for many values of L/R of the circuit; (d) independent of the speed of separation of contacts in the range of 7.5 to 90 inches per second; (e) dependent upon the pressure of the atmosphere in which the arc is burned; (f) dependent upon the ionizing potential of the electrode; and (g) dependent upon the electrode coating.

The following are values obtained for the cathode drop for various electrodes, compared with the respective ionizing potentials.

| Electrode | Cathode Drop (volts) | Ionizing Potential (volts) |
|---|---|---|
| Aluminum | 11.2 | 5.96 |
| Silver | 12.5 | 7.53 |
| Copper | 13.0 | 7.68 |
| Iron | 13.4 | 7.83 |
| Platinum | 17.6 | 8.9 |
| Mild Steel (Coated) | 10.1-10.9 | ..... |
| Stainless Steel (Bare) | 15 | ..... |
| Stainless Steel (Coated) | 13.3 | ..... |
| Tobin Bronze | 11.0 | ..... |
| Beryllium Alloy | 13.7 | ..... |

The cathode drop for copper was found to decrease from 13 volts at atmospheric pressure to 8 volts at .1 mm. of Hg.

The following theory is set up to explain the results obtained. At the instant of separation of contacts the "last" contact is heated to a temperature of at least 3000°K and perhaps higher. This high temperature creates a sufficient supply of positive ions in the vicinity of the cathode to form a space charge. The ions are chiefly formed from air molecules at atmospheric pressure with only a small number of metallic ions. At low pressures the converse is true.

The positive ion space charge so formed removes electrons from the cathode by field emission. These electrons carry substantially all the arc current.

The fraction of molecules which are ionized may be computed from Saha's equation[4] if for the ionizing potential is substituted the value of the cathode drop observed (13 volts for copper). The value of ionizing potential used is assumed to represent a weighting of the effects of the few copper ions present (ionizing potential 7.68 volts) and the many nitrogen ions present (ionizing potential 16.5 volts). Knowing the pressure of the arc atmosphere enables one to compute the number of positive ions present. The mobility of the positive ions is so low that the number striking the cathode accounts for only .3% of the total number of carriers of current.

With this in mind, and using the observed value of arc current density at the cathode (which was estimated at about 5000 amperes per sq. cm. for copper at one atmosphere) the electron density in the intervening space between cathode and positive ion space charge can be determined.

The application of Poisson's equation to the problem permits the calculation of the average electric field and the length of the "cathode drop space." These values are 29000 volts per cm. and .00045 cm. for atmospheric pressure, and 250000 volts per cm. and .000314 cm. for .1 mm. Hg. (for copper electrodes) respectively.

The average electric field computed is sufficient to give field emission of electrons if the temperature of the electrode is high when current conduction takes place. The length of the "cathode drop space" is much smaller than can be measured experimentally.

The time for the cathode voltage drop to reach the value given was estimated in two ways. By applying a 60 cycle alternating voltage to the separating contacts and synchronizing the sweep of the cathode ray oscillograph to this frequency the voltage across the contacts appeared as a stationary pattern. There was no observed time lag between the breaking of contacts and the establishment of the arc, at least within 50 microseconds. By applying both current and voltage of the arc to the oscillograph, noting the change in voltage and current as the arc was established, and knowing the electrical constants of the circuit the time for arc establishment was estimated as about 100

microseconds. These values indicate that equilibrium occurs sooner than expected from the data supplied by Duddell[5] on the superposition of an a-c arc on d-c arc, and the data of Witte,[6] 600 microseconds, from spectral data.

The data obtained experimentally showed that if the arc open-circuit voltage was less than the cathode drop no arc could be observed unless the circuit contained inductance. When the latter was true the contact voltage jumped to the cathode drop value until the arc was extinguished.

The magnitude of the cathode drop is of practical importance in arc discharges. The speed of extinction of the a-c arc in low voltage switches depends upon the amount of energy in the arc and on how fast this energy is dissipated. The energy of the arc varies directly with the cathode drop. Hence, if other factors are equal, the electrode material with the lowest cathode drop is best. If a d-c arc is to be extinguished, the highest cathode drop will be most satisfactory since the larger the drop the easier it is to make the arc unstable.

Silver is a satisfactory contact material for a-c switches, while the beryllium alloy and platinum noted above are satisfactory for d-c switches.

The second application of the knowledge of the cathode drop of the arc is in the field of arc welding. The methods developed here provide a quick and simple way of noting the effect of electrode coatings and alloys on the cathode drop. The magnitude of the cathode drop determines in part the heat distribution at the cathode and anode.

## References


1 Compton, K. T., Trans. A. I. E. E. **46**, 868, 1927
2 Mason, R. C., Phys. Rev. **51**, 28, 1937
3 Betz, P., and Karrer, S. J., J. Applied Phys. **8**, 845, 1937
4 Saha, M. N., Phil. Mag. **40**, 472, 1920
5 Duddell, W., Proc. Roy. Soc. **A68**, 512, 1901
6 Witte, H., Zeits. f. Phys. **88**, 415, 1934

## VITA

Gilbert Howard Fett was born in Chicago, Illinois, June 19, 1909. His parents are Charles G. Fett and Frieda G. (Klein) Fett of Chicago.

He was educated in the elementary schools of Chicago, and was graduated from Lane Technical High School in June, 1925. He attended Armour Institute of Technology Evening School from 1925 to 1927, Crane Junior College of Chicago from 1927 to 1929, and the University of Illinois from 1929 to 1931. From the latter school he received the degree of Bachelor of Science in Electrical Engineering with High Honors.

He subsequently received a Master of Science degree from Iowa State College in August, 1932. From 1933 to 1935 he attended the University of Chicago, registering in courses in physics and education given on Saturdays, the late afternoons and evenings. From 1935 to date he attended the University of Illinois part time.

His professional experience includes working as draftsman and experimental worker with Justrite Mfg. Co., Chicago, from 1925 to 1929; graduate assistant in electrical engineering at Iowa State College, 1931 to 1932; research engineer with Littelfuse Laboratories, Chicago, 1933 to 1935; assistant in electrical engineering, University of Illinois, 1935 to 1937; instructor in electrical engineering, University of Illinois, 1937 to date; and junior engineer with the Federal Power Commission during the summer of 1937.

He is a member of the American Institute of Electrical Engineers (Member Grade), Tau Beta Pi, Sigma Xi, Phi Kappa Phi, Eta Kappa Nu, and Pi Mu Epsilon.

He is the author of a number of papers and articles and the co-author of one book.

In 1936 he married Miss Genevieve Helen Weninger of Chicago, Illinois. The couple have one daughter.